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Sandia National Laboratories

ParaChoice Model

Project ID#: VAN019

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Sandia National Laboratories

DOE Annual Merit Review, June 8th, 2017

This presentation does not contain any proprietary, confidential, or otherwise restricted information

Overview

Timeline and Budget

- Start date: FY14
- End date: Project continuation determined annually
- FY14-16 Budget: $580k
- FY17 Budget: $350k
  - Received*: $194k
  - Spent*: $127k

  *as of 3/31/2017

Barriers (from VTO MYPP 2011-2015)

- Availability of alternative fuels and station infrastructure (*A*)
  - Lack of fueling infrastructure to compete with the fully mature conventional petroleum-based fuels
  - Few electric charging stations needed for the coming plug-in hybrid electric vehicles (PHEVs) and fully electric vehicles (EVs)
- Availability of AFVs (*B*)
  - OEM supply limitations for technologies such as CNG
  - Cost limitations for technologies such as PHEVs
- Consumer reluctance to purchase new technologies (*C*)
  - Uncertainties in value proposition for OEMs & buyers
- Increase Class 8 truck freight hauling efficiency by >50% (VTO SuperTruck Goal)

Partners: Interactions / Collaborations:

- Ford: Real World Driving Cycles
- Toyota
- American Gas Association
- DOT
- ANL, ORNL, NREL, LBNL, Energetics
- North American Council for Freight Efficiency (NACFE)

Relevance & Objective

- ***Lifetime project goal***: System-level analysis of the dynamics among the light & heavy-duty vehicle (LDV & HDV) fleets, fuels, infrastructure mix, and emissions
  - Use parametric analysis to:
    - Identify trade spaces, tipping points & sensitivities
    - Understand & mitigate uncertainty introduced by data sources and assumptions

Addresses barrier A

- ***HDV***: Evaluating the potential for AFVs to increase freight hauling efficiency & reduce pollution
  - Added model capability to handle vocational HDVs

New FY17 Analysis

Addresses VTO ST Goal

- ***LDV***: Determine the impact of both public and workplace EV charging infrastructure on EV adoption and use
  - Scenario analysis for level 2 and DC fast public charging stations
    - Baseline & three scenarios with level 2 or DC fast station deployment
  - Parametric analysis for public EV charging infrastructure
    - Studied DC fast charger deployment nationally and state-by-state
  - Parametric analysis for workplace EV charging
    - Monte Carlo uncertainty analysis (people vs. miles; access vs. range)

Addresses barriers A & C

Follow up on 2016 AMR preliminary results

New FY17 Analysis

- ***Updates***: AEO 2016, Moawad *et al.*, and GREET 2016

Milestones

Date	Milestones and Go/No-Go Decisions	Status
FY17 Q1	*Milestone* Complete parametric sensitivity study of charging infrastructure availability for discussion with DOE/VTO	Complete
FY17 Q2	*Milestone* Solicit feedback on LDV parametric sensitivity study and refine accordingly summarize feedback and proposed refinement to HQ	Complete
FY17 Q3	*Milestone* Compose journal article based on parametric sensitivity study	On track pending funding
FY17 Q3	*Go/No-Go Decision* Assess project for meeting DOE criteria for 1) solving a long-term, difficult challenge, 2) providing a unique capability, and 3) being relevant to the EERE mission.	On track
FY17 Q4	*Milestone* Develop online interface to selected model results	On track

Approach: ParaChoice – Underlying systems model between energy and LD or HD vehicles

Begins with today's energy, fuel, and vehicle stock and projects out to 2050. At each time step, vehicles compete for share in the stock based on value to consumers.

Energy demand

Fuel demand

ENERGY
Oil
Coal
Natural Gas
Bio Mass
Nuclear/wind/solar

FUEL
Gasohol ***E85***
Diesel ***B20***
CNG & LNG
Electricity (grid)
H_2 (five fuel pathways)

VEHICLE STOCK

Parameters as *f*(t):
- Veh. costs & efficiencies
- Model availability
- Infrastructure evolution
- Stock size
- Powertrain prevalence
- Emissions

Red = endogenous

Prices evolve

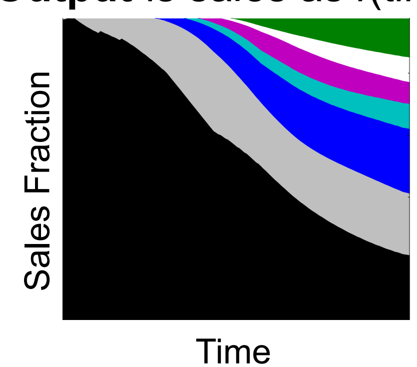
Energy prices

Fuel prices

Baseline inputs
- Energy prices: AEO 2016
- Emissions: GREET
- Fleet segmentation: NHTS (LDV); Polk (HDV)
- Vehicle price projections: Autonomie (LDV); National Petroleum Council (HDV)
- 2010-2017 fueling stations: AFDC
- Policies (by state): AFDC

Policy options as *f*(t):
RFS, carbon taxes, H_2 production pathways, electric grid composition

Output is sales as *f*(time)



Approach: At every time step, simulation assesses generalized vehicle costs for each vehicle. Choice function assigns sales based on these costs and updates stock.

VEHICLE STOCK

Vehicle	Generalized Vehicle Cost	Percent of Sales
Conv. SI	$X /year	A %
FCEV	$Y /year	B %
PHEV40	$Z /year	C %

… And 17 more

Given:
- Input attribute(s)
- Fixed set of 2+ output choices

Nested Multinomial Logit Function

Outputs:
- Probability distribution

Generalized Vehicle Cost

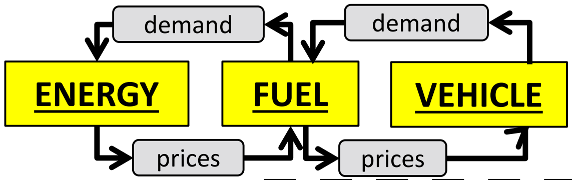
Upfront Costs Amortized Over "Required Payback Period"

- Purchase price
- One time incentives
- One time penalties *(Infrastructure penalty)*

Recurring Costs

- Fuel cost
- Annual incentives
- Annualized penalties *(Range penalty)*

Approach: Segment vehicles, fuels, & population to understand competition between powertrains & market niches



Demographics | *Vehicle* | *Geography*

LDV Segmentation

Powertrain
20 Powertrains

Housing type
With or w/o access to charging/ fueling

Driver Intensity
Low, Med, or High

VMT Segmentation

Energy/Fuel Seg.

State
48 CONUS +
Washington, DC

Density
Urban
Suburban
Rural

Size
5 Sizes

Age
0-46 years

HDV Segmentation

Powertrain
CI (4 Types)
CNG (3 Types)
LNG (2 Types)

Refueling Type
Gas Station
Truck Stop
Private

Age
0-18 years

GVW
Class 7 & 8

Body Type
Tractor Trailer
Straight Truck
Bus

(Vocation)
Construction
Food
General Freight
Lease/ Finance
Manufacturing
Natural Resources
Services
Wholesale/Retail

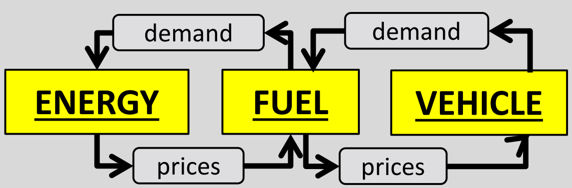
Fleet Size
1-9; 10-99;
100-999;
1,000+

State
48 CONUS +
Washington,
DC

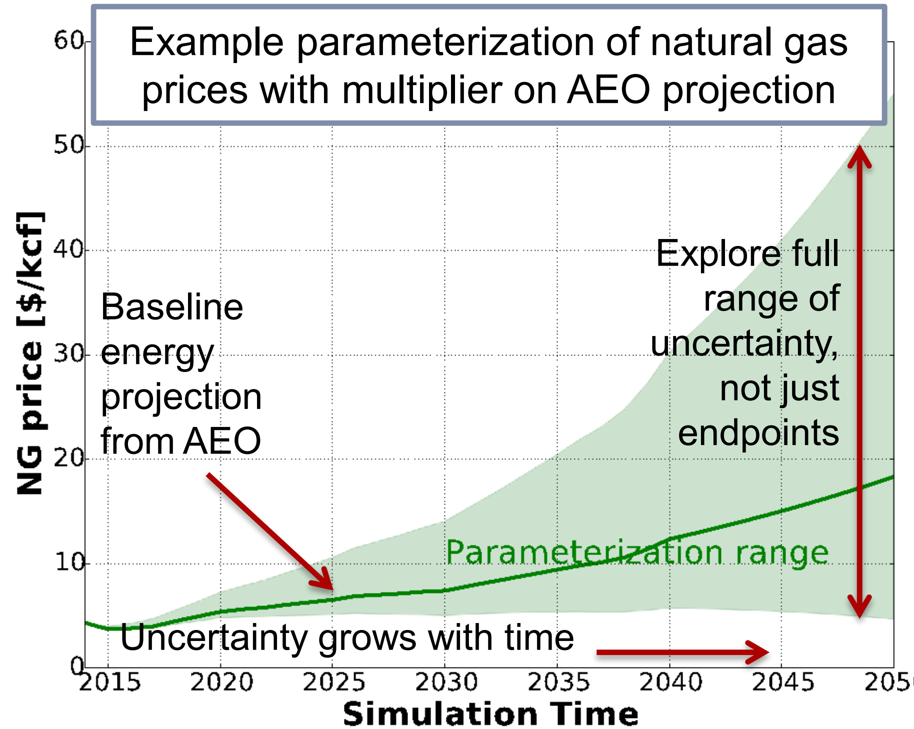
Approach: Use parameterization to understand and mitigate uncertainty introduced by data sources and assumptions

***Uniqueness from other DOE models*:**
ParaChoice is designed to explore uncertainty & trade spaces, easily allowing identification of tipping points & sensitivities

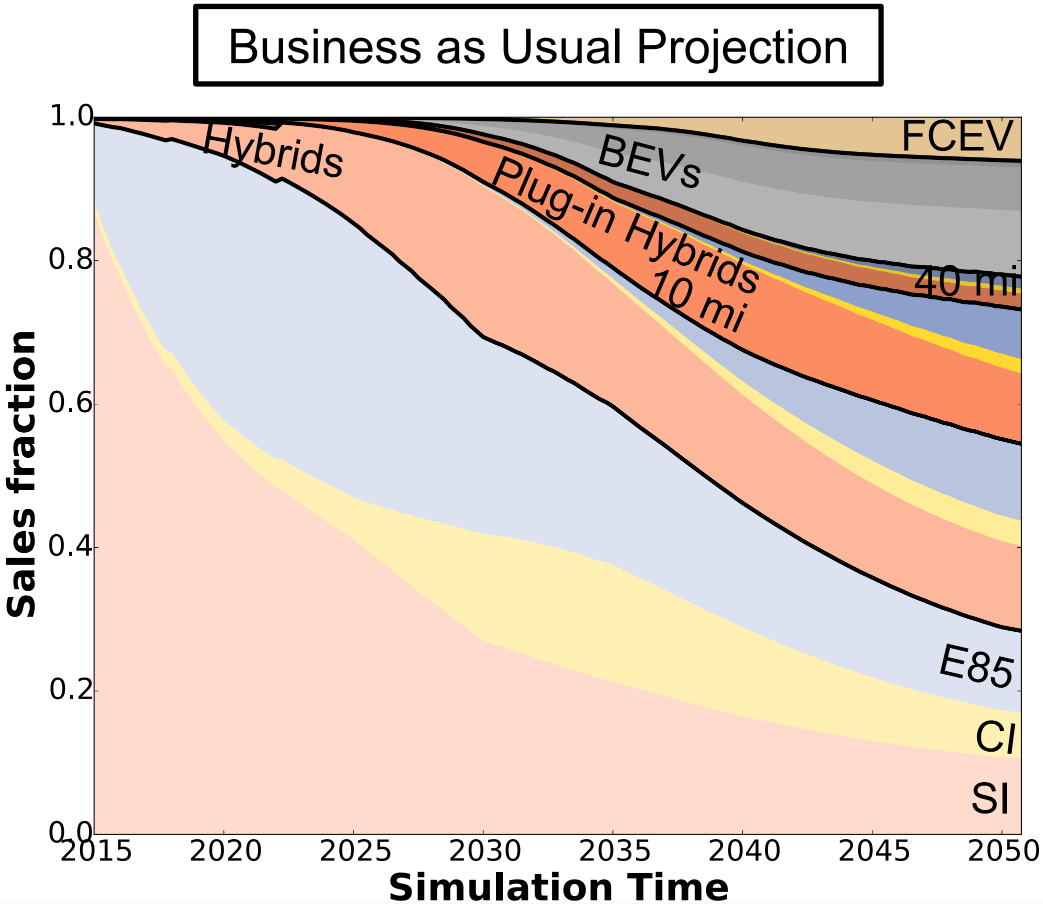
- Core simulation is a system-level analysis of dynamic, economic relationship between energy, fuels, & vehicles with baseline values from trusted DOE sources. Technologies compete in the simulation, are allowed to flourish or fail in the marketplace.

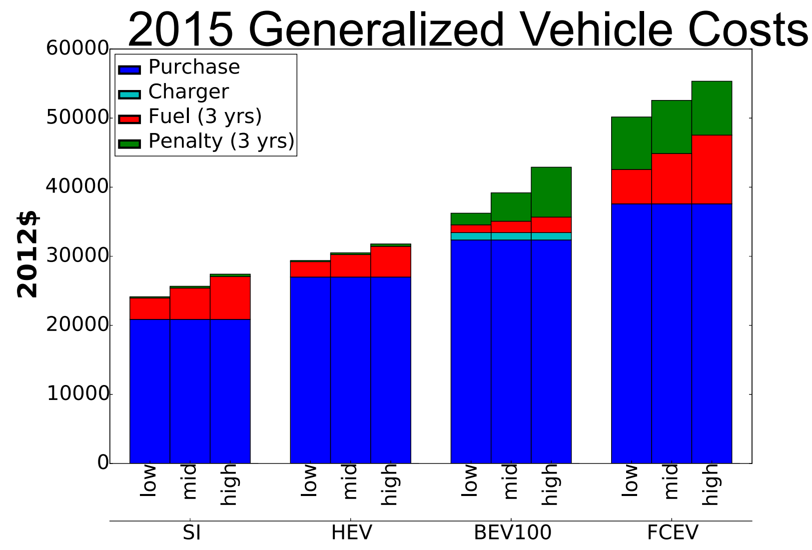


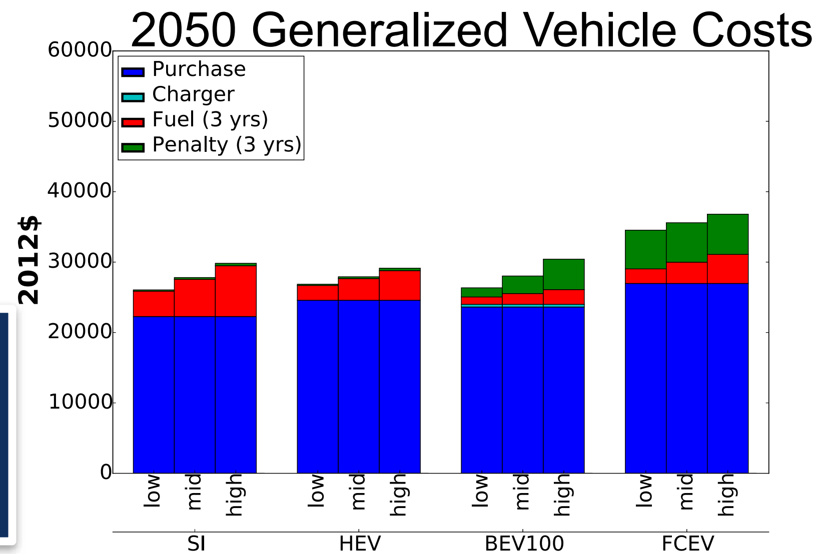
- Simulation is run 1000s of times with varying inputs. This parametric analysis provides:
  - Perspectives in uncertain energy & technology futures
  - Sensitivities and tradeoffs between technology investments, market incentives, and modeling uncertainty
  - The set of conditions that must be true to reach performance goals



- Vary two parameters at once- trade space analysis (~400 scenarios)
- Vary many parameters- sensitivity analysis (~3000 scenarios)
- Parameterization ranges designed to explore plausible AND 'what if' regimes, covering all bases







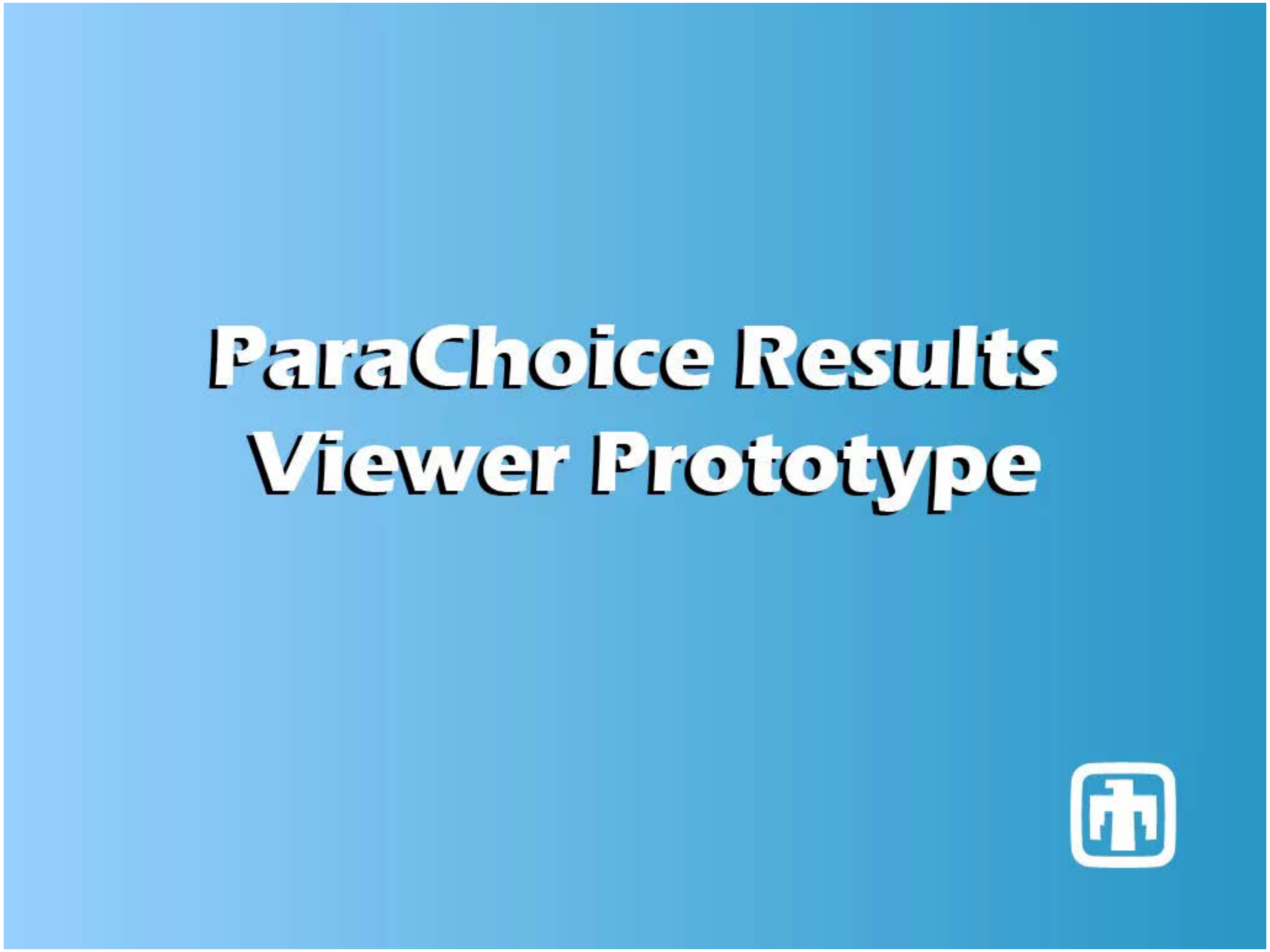
Key results:

Modest penetration of BEV 75, 100, & 200 (~14%) by 2050 due primarily to a decrease in BEV purchase cost and fuel cost advantage to petrol.

Baseline cost assumptions from Autonomie & AEO

Scenario projections are NOT the goal of the model, but a starting point for understanding market drivers

Accomplishments & Progress: Results Viewer and Baseline Results



A&P Public Charging: Station injection scenarios show impact on BEV sales and electrified mileage

Powertrain (PT)	Baseline 2050 PT Sales Fraction (%)	Injecting 500K Level 2 (Δ%)	Injecting 50K DC Fast (Δ%)	50K DC Fast + 10¢/kWh Elec. Surcharge (Δ%)
SI, CI and E85	29	-1	-2	0
Hybrids	26	0	-1	+1
Plug-in Hybrids	24	-1	-3	-1
BEVs	16	+1	+7	-1
FCEV	6	0	-1	0
% of All Fleet Miles Electrified	15	+1	+8	+1

Absolute #s are not important; insights come from changes in sales fraction relative to baseline (Δs) among the various scenarios.

Level 2 charging does very little to promote BEV sales relative to DC fast.

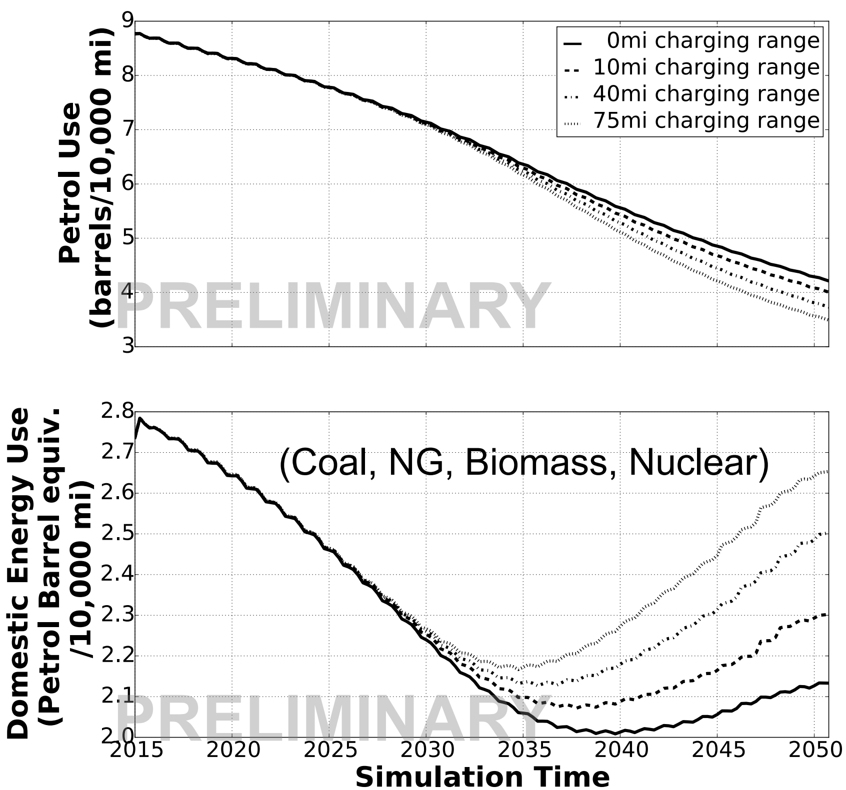
10¢/kWh elec. surcharge severely dampens sales and electrified mileage gains

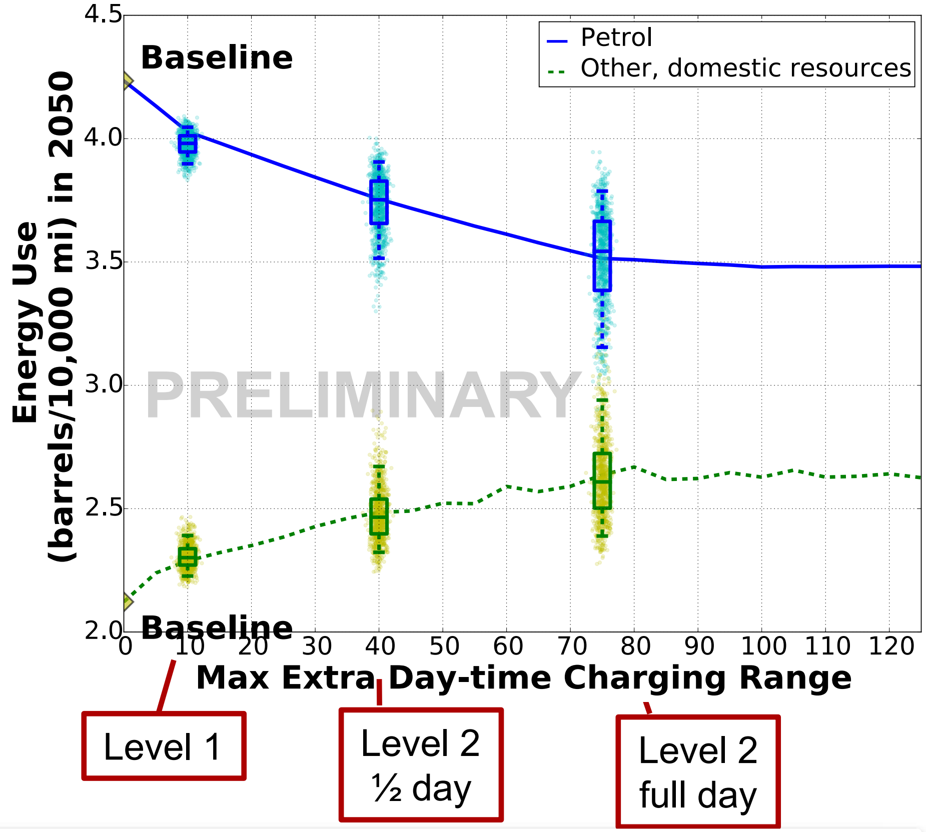
Key results:
For large scale national deployment strategies, <u>public</u> DC fast chargers will promote BEV sales more effectively than public level 2 chargers, increase electrified mileage, and lower GHG emissions, even if only one DC fast charging station is built for every ten level 2 charging stations.

 Energy savings for convenient charging

Analysis Strengths

1. Incorporating and analyzing DOE strategies for targeted infrastructure at the workplace
2. Recognizing the potential weaknesses of traditional infrastructure models for AEVs
3. Monte Carlo analysis to understand limitations of assumptions & confidence in trends.





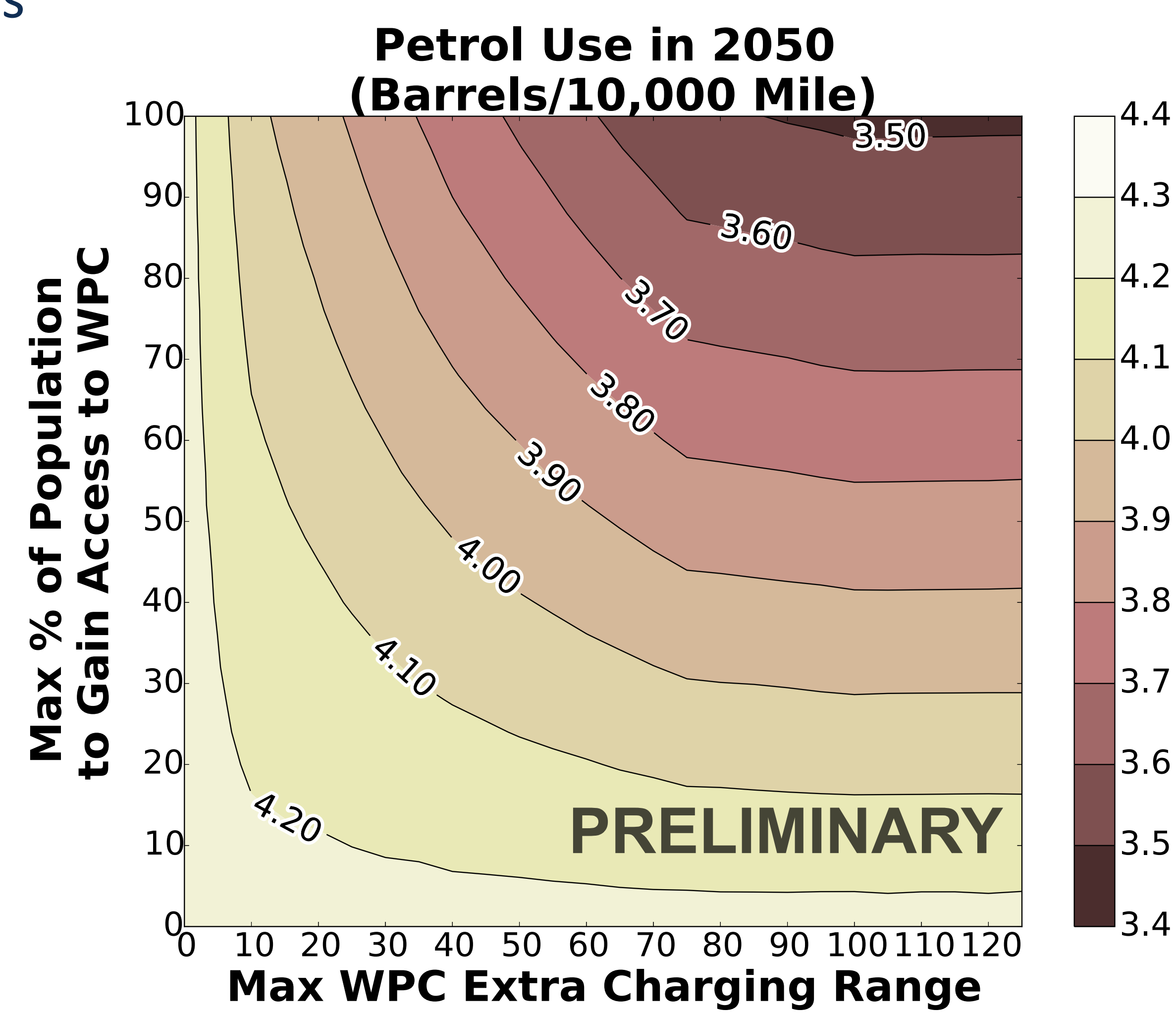
Key Result:

As we increase the day-time charging range that is conveniently & reliably available to the population, fleet-wide petrol use will drop in favor of other, purely domestic resources.

A&P Workplace Charging 2: Workplace charging accessibility versus range tradespace analysis

Analysis strengths

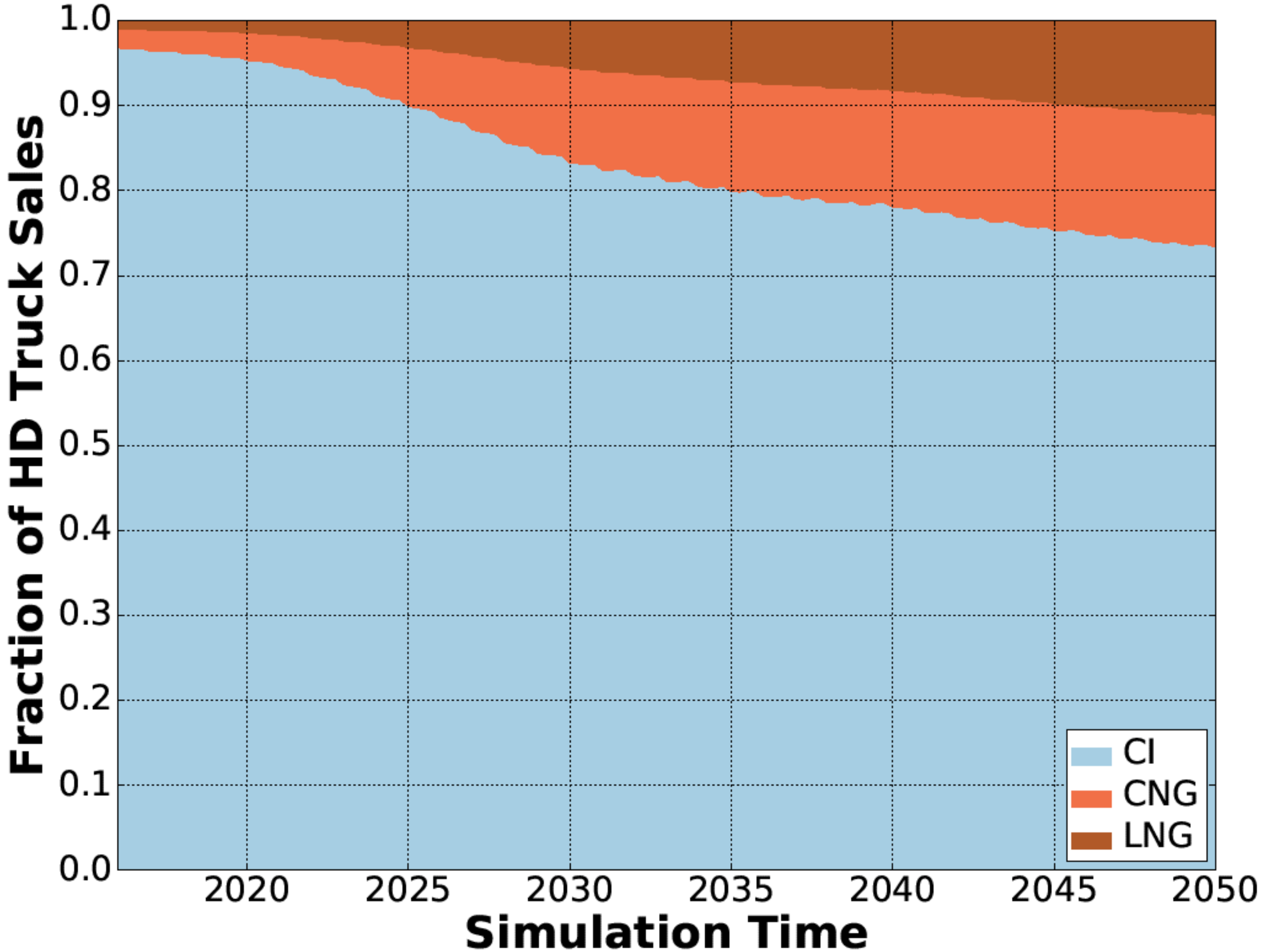
1. Fraction of population with access to workplace charging is an evolving, parameterizable, modeling segment.
2. Tradespace analysis informs policy decisions



Key Result:
A large percent of the population needs access to reliable level 2 workplace charging in order to significantly reduce petrol use by 2050.

A&P HDV Analysis 1: Natural gas incentives only subtly impact heavy-duty vehicle powertrain adoption

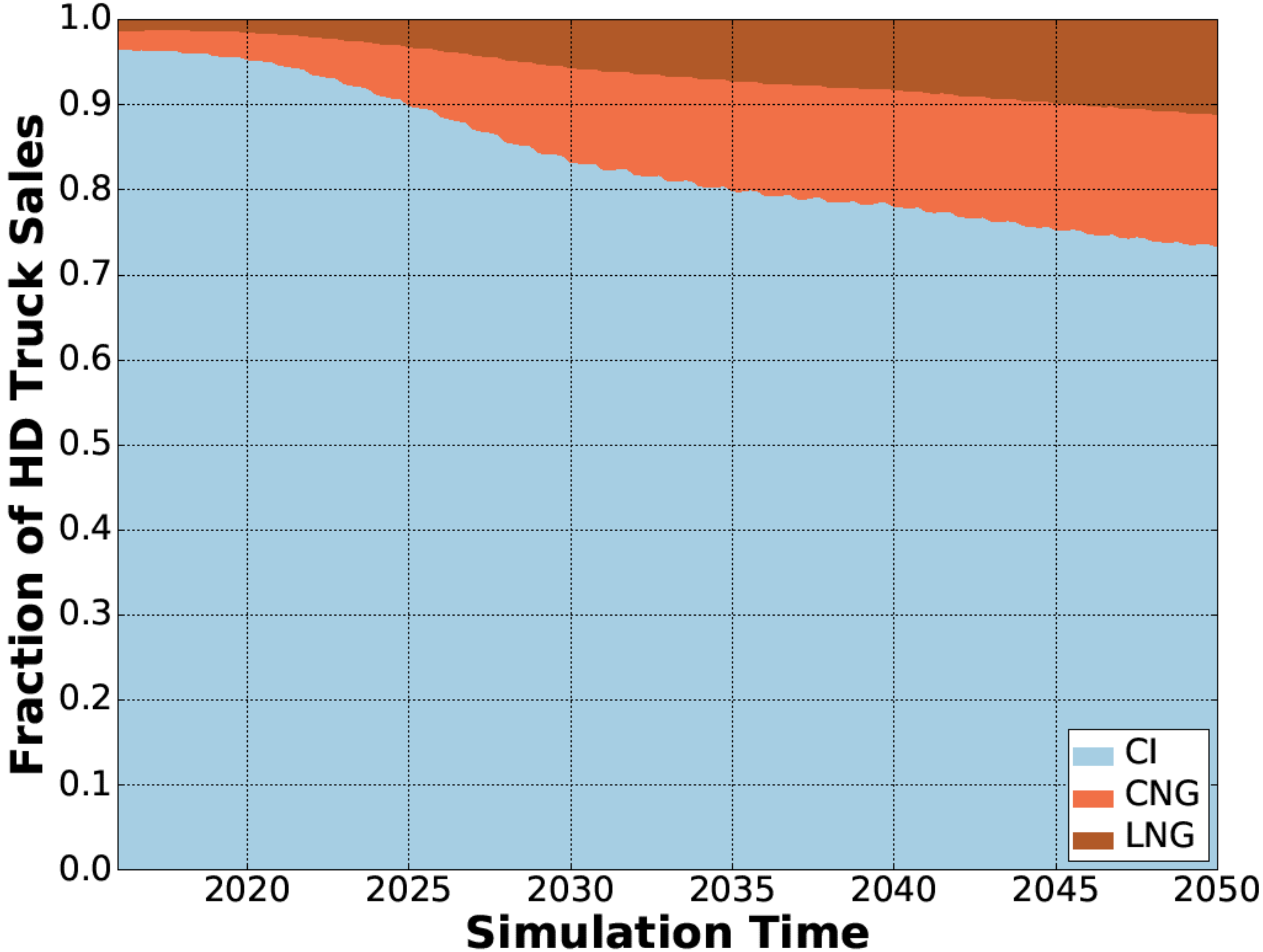
- Baseline: Approx. 1/4 HDVs are NG powered



Without NGV Incentive

A&P HDV Analysis 1: Natural gas incentives only subtly impact heavy-duty vehicle powertrain adoption

- Baseline: Approx. 1/4 HDVs are NG powered
- No change with $0.50 incentive through 2016



$0.50 NGV Incentive Through 2016

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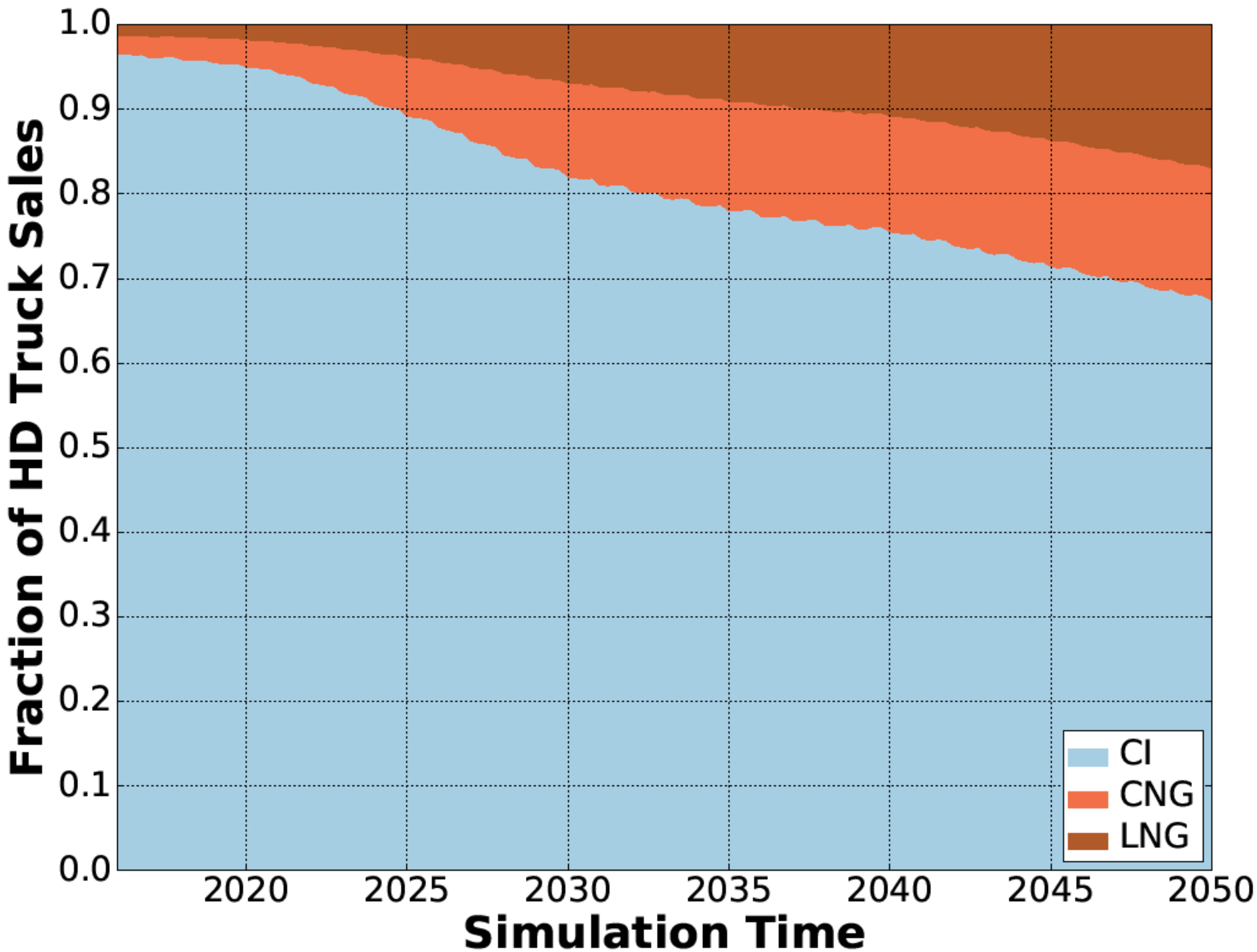

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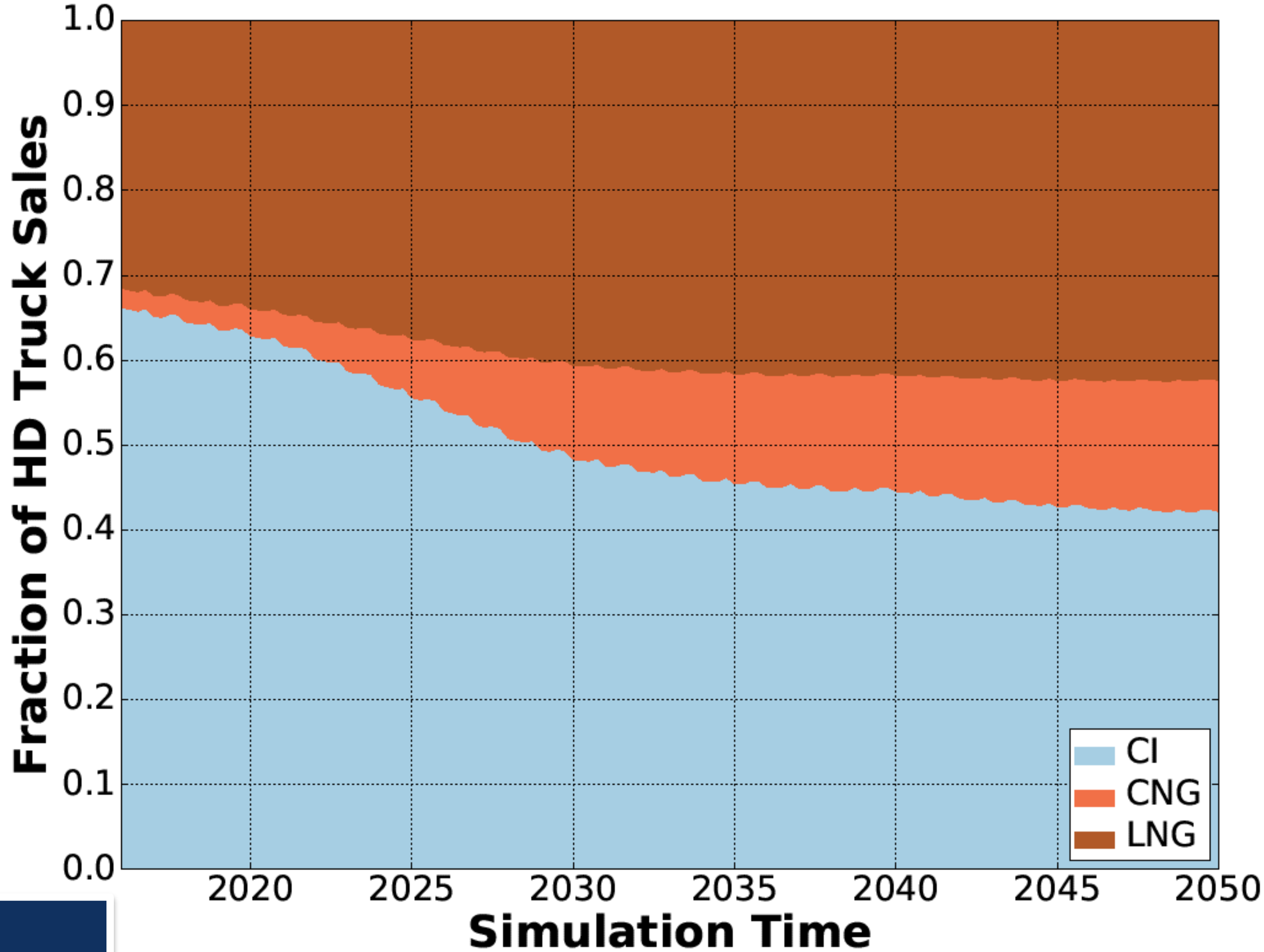
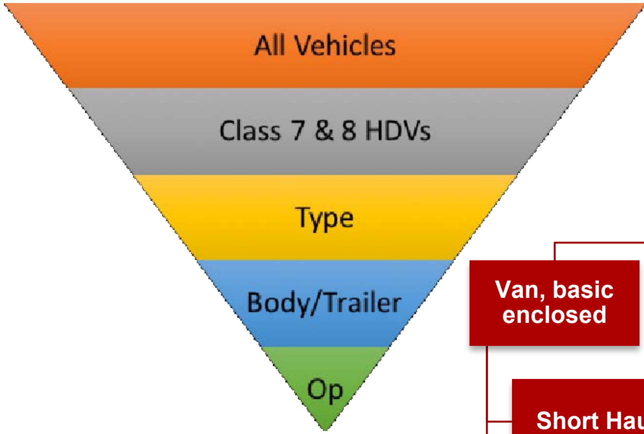
- Growth is primarily in LNG vehicles

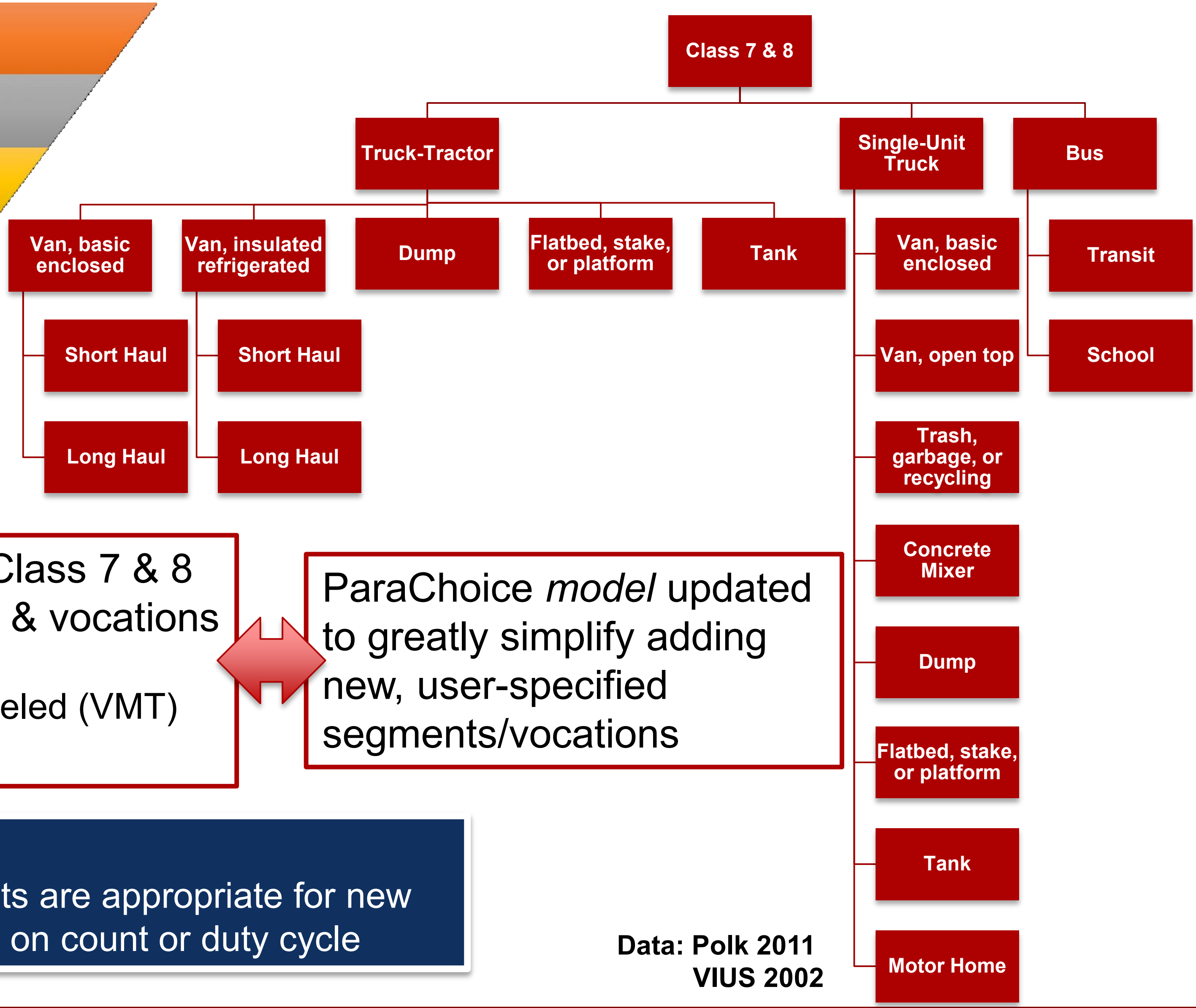


$3.00 NGV Incentive Through 2050

Key Result:
Practical NGV incentives have minimal impact on adoption

A&P HDV Analysis 2: ParaChoice model and data updates to assess impacts of new technologies for Class 7 & 8 HDVs





Collected *data* on Class 7 & 8 HDV segmentation & vocations

- Vehicle Count
- Vehicle Miles Traveled (VMT)
- Fuel Consumption

ParaChoice *model* updated to greatly simplify adding new, user-specified segments/vocations

Key Result:
Only some segments are appropriate for new technologies based on count or duty cycle

Data: Polk 2011
VIUS 2002

A&P HDV Analysis 3: Alternative energy technology benefits depend on the HDV fleet and drive cycle characteristics

HDVs are significant contributors to air pollution (e.g. NO_x)

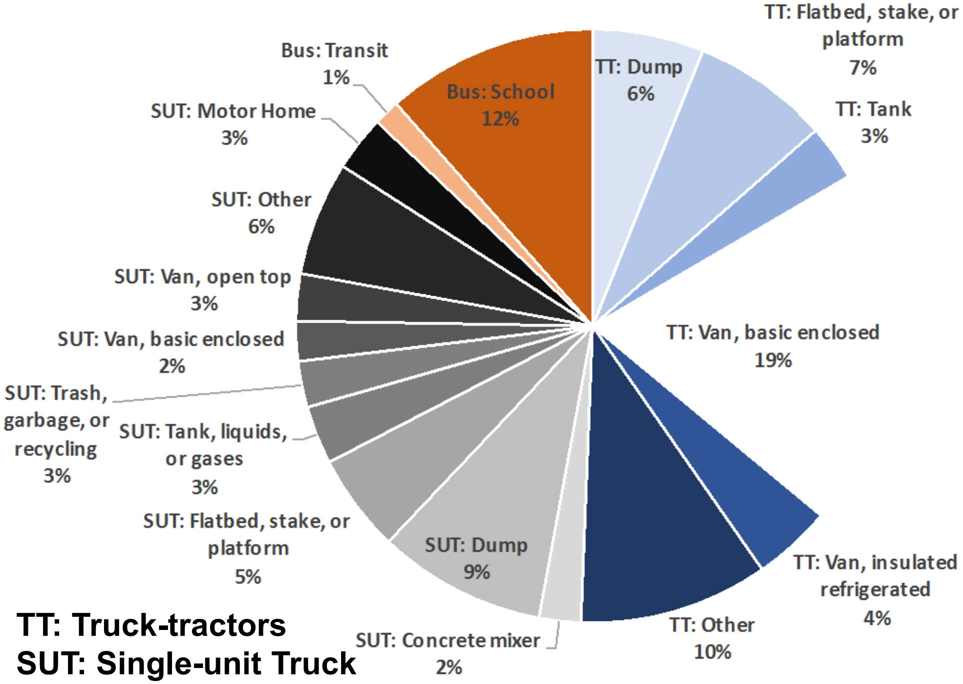
$$\begin{Bmatrix} Technology \\ Benefit \end{Bmatrix} = \begin{Bmatrix} Market \\ Size \end{Bmatrix} \times \begin{Bmatrix} Savings/ \\ Reduction \end{Bmatrix}$$

Count | VMT

Fuel Use
Tractive effort
Idling
Vocational load

Pollutants
NO_x
SO_x
PM

Alternative energy technologies impact one or more of these in different ways



TT: Truck-tractors
SUT: Single-unit Truck

The HDV fleet is heterogeneous

- Vocational HDVs are ~30% of market
- ~40,000-60,000 built per year
- 100s of unique applications → small sales volume for each application
- Most OEMs develop a common chassis rather than building 100+ unique

Response to previous year reviewers' comments

Comments from the FY15 AMR	Response
The reviewer said that the parametric analysis provides useful insights that can guide VTO decisions and those of other stakeholders, but validation of the various parts of the model and input assumptions could be improved.	**Actions Taken** Performed a validation study in 2016 showing the soundness of ParaChoice simulations by comparing simulated AEV sales to historical data. **Status**: Complete
One area that could improve the value is to conduct (or show) more sensitivity and uncertainty analysis on what the research identifies as the most influential factors or relationships.	**Actions Taken** Added explicit Monte Carlo analysis and results plotting capabilities to augment sensitivity and tradespace analyses. **Status**: Complete
The reviewer recommended digging deeper into the relationship between infrastructure and BEV and PHEV attractiveness, but was unclear whether the model includes different electric vehicle supply equipment (EVSE) power levels.	**Actions Taken** Studied impacts of level 2 and DC fast public EV charging infrastructure availability. Studying the impact of workplace/convenient EV charging. **Status**: Public Complete; Workplace On track
The reviewer stated that one piece missing from future work is improvement to data visualization. The reviewer believed even these could become more compelling with, for example, animated graphs (that pivot, rotate, or change in time), or the many other emerging methods	**Actions Taken** Developing an interactive, online results viewer for users to explore data from our published work. Future development could include viewing of Monte Carlo, tradespace, and HDV analyses. **Status**: On track

Collaborations

- No funding given to other institutions on behalf of this work
- Technical critiques received from Ford Motor Company, General Electric, American Gas Association, and other conference engagements
- The underlying ParaChoice model has been developed using funding from a variety of sources including
  - Sandia Laboratory Directed Research & Development Funds
  - Clean Energy Research Consortium
  - Vehicle Technologies Office
- Collaboration on BaSce, a cross-lab model comparison for baseline & DOE program success scenario cases, led by Tom Stephens (ANL)
- This work is complemented by modeling and analysis for the FCTO. Rebecca Levinson will be presenting on FCTO-funded ParaChoice analysis (project ID SA055) Thursday June 8 at 4:45 PM

Remaining Challenges and Barriers

- Many individual components contribute to generalized vehicle cost and, therefore, market share for each vehicle powertrain. A primary challenge is identifying which of these most significantly improve market share as well as measured outcomes such as fuel use and emissions. Elucidating these factors would help determine the relative value of technologies to improve each.

- There will likely not be a single technology that produces benefits across all segments of the heterogeneous heavy-duty vehicle fleet. The operating characteristics and number of vehicles in each segment determine the impact novel technologies may have in improving measured outcomes. The challenge, therefore, is to elucidate which technologies and investments (on which HDVs) provide the greatest return and value propositions for HDV operators. Some of these technologies may also require investments in public infrastructure development.

Proposed Future Work

- Market level analysis of vehicle component benefits in complement to ANL "Evaluation of Individual Vehicle Technologies Office Benefits on Standard Drive Cycles" **Joint effort with ANL analysis team**
  - Assess the benefits of VTO vehicle component level research by determining the detriment of defunding DOE-supported research into individual vehicle technologies
    - Quantify the impact each technology has on US petrol consumption, energy expenditure, cost to consumers, and GHG emissions
  - Account for synergistic effects between individual vehicle technologies in showing the impact of cost cutting decisions on the technologies in the VTO portfolio
- Quantitatively characterize the fleet of HDVs on the road (count + drive cycle) to identify the potential for technology to improve fuel efficiency and air quality
  - Identify the "beachhead market(s)" where alternative energy technologies would provide the greatest benefit and commercial viability

Milestones:

Compose journal article for peer review by end of FY17 Q3

Develop online interface to selected model results by end of FY17 Q4

Any proposed future work is subject to change based on funding levels and direction from VTO program managers

Summary

- ParaChoice
  - Is a **validated system level analysis model** of dynamic between vehicles, fuels, & infrastructure
    - **Leveraging other DOE models and inputs**
    - Simulating fuel production pathways that scales with fuel demand
  - Is **designed for parametric analysis** in order to
    - **Understand & mitigate uncertainty** brought in by data sources and assumptions
    - Identify trade spaces, tipping points & sensitivities
  - Helps us understand changes to the LDV and HDV stocks, fuel use, & emissions
  - Is NOT simply a tool for creating scenario sales projections
- Analysis key results:
  - Public Charging
    - Start to see diminishing ROI after deploying approximately 30K public DC fast chargers
    - Public DC fast charging infrastructure may increase fleet-wide electrified mileage by ~8%
    - No more than a 12¢/kWh total effective surcharge should be passed to EV drivers
  - Workplace Charging
    - Increasing the availability of daytime charging decreases petrol use and favors domestic energy
    - Much of the population needs access to level 2 workplace charging to significantly reduce GHGs
  - HDVs
    - Natural gas incentives only subtly impact HDV powertrain adoption
    - The HDV fleet is heterogeneous; vehicle count and drive cycle impact efficiency and emissions
- Future work will show the impact of VTO investments in component technologies on fuel consumption and emissions as well as the potential for alternative technologies for HDVs

Technical Back-Up Slides

Approach: How ParaChoice models infrastructure, or lack thereof

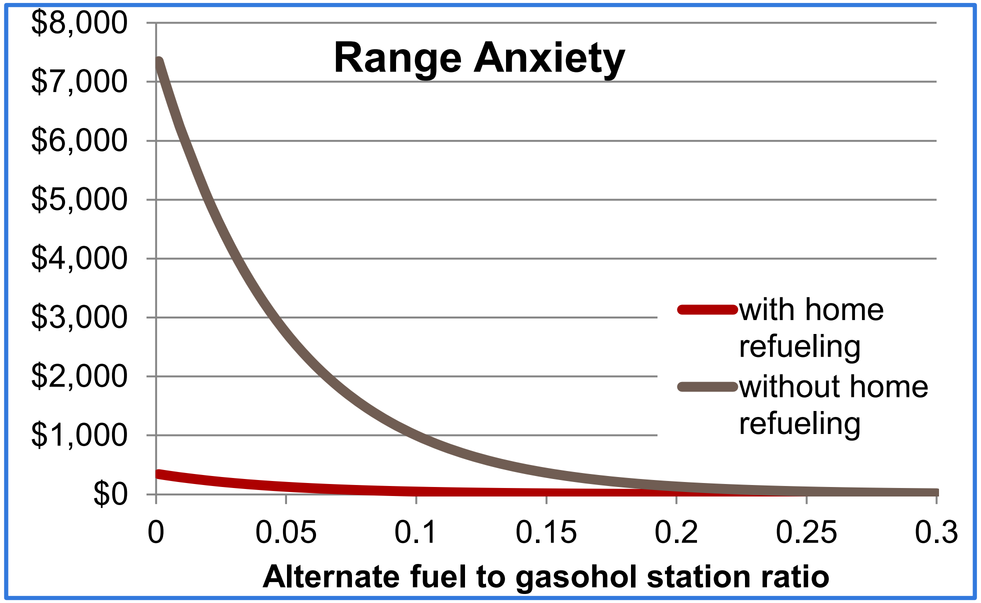
- For public infrastructure, charging outside of home is inconvenient. BEV drivers may opt to:
  - Use an alternate vehicle for long trip days[2]

    Penalty = $Rental vehicle cost *x* number of days driving beyond BEV range

OR

- Use EV infrastructure, tolerating[1]
  - range anxiety due to station scarcity and
  - charging times

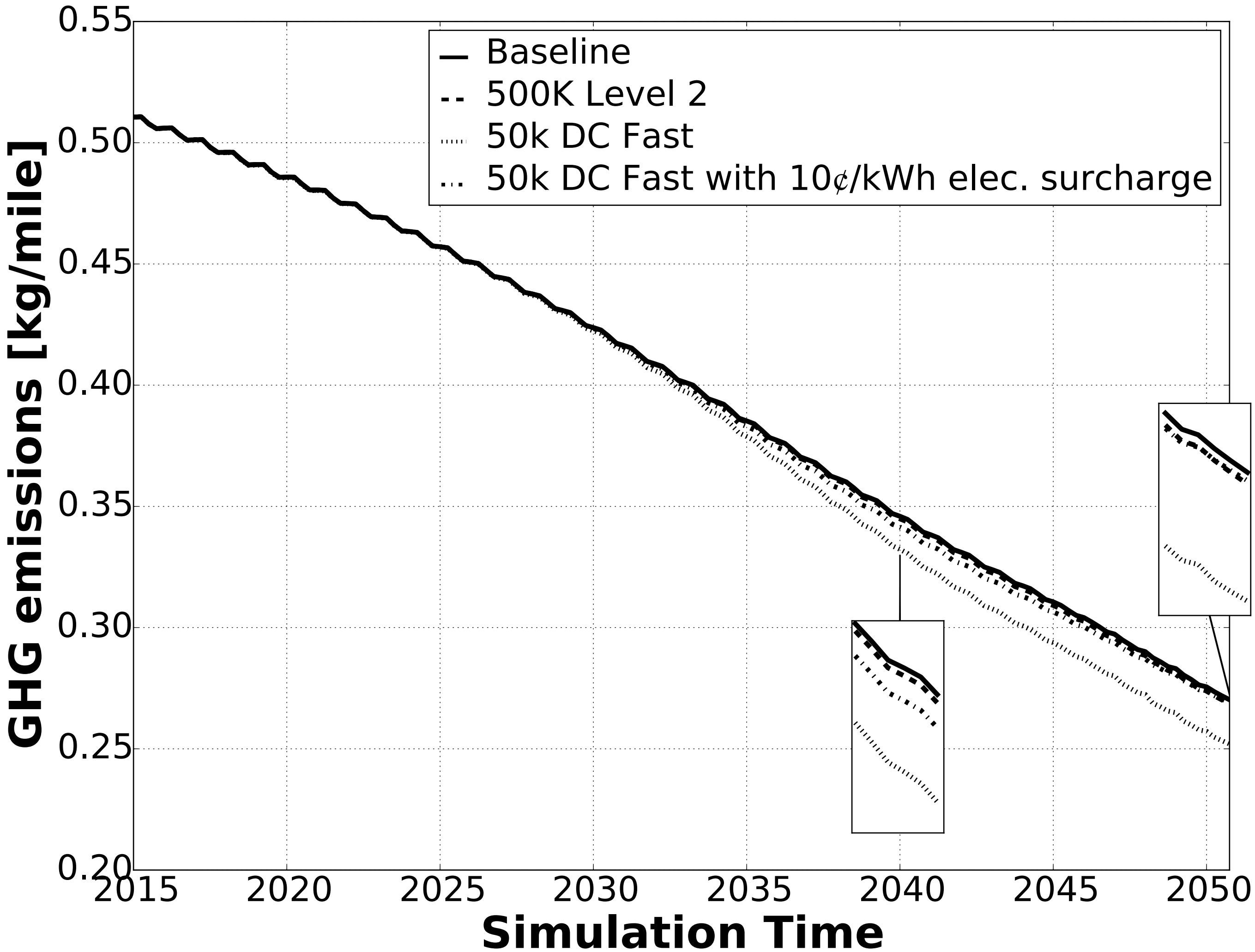
    Penalty = $Value of time *x* (hours refueling inconveniently)



- Workplace-type charging is convenient, and has different impacts
- No explicit monetization for EV infrastructure's beneficial impact on consumer 'awareness' of EVs

D. L. Greene. TAFV Alternative Fuels and Vehicle Choice Model Documentation. ORNL 2001.
G. E. Barter, M. A. Tamor, D. K. Manley, and T. H. West. *TRR Journal*, (2502):80–88, Sept. 2015.

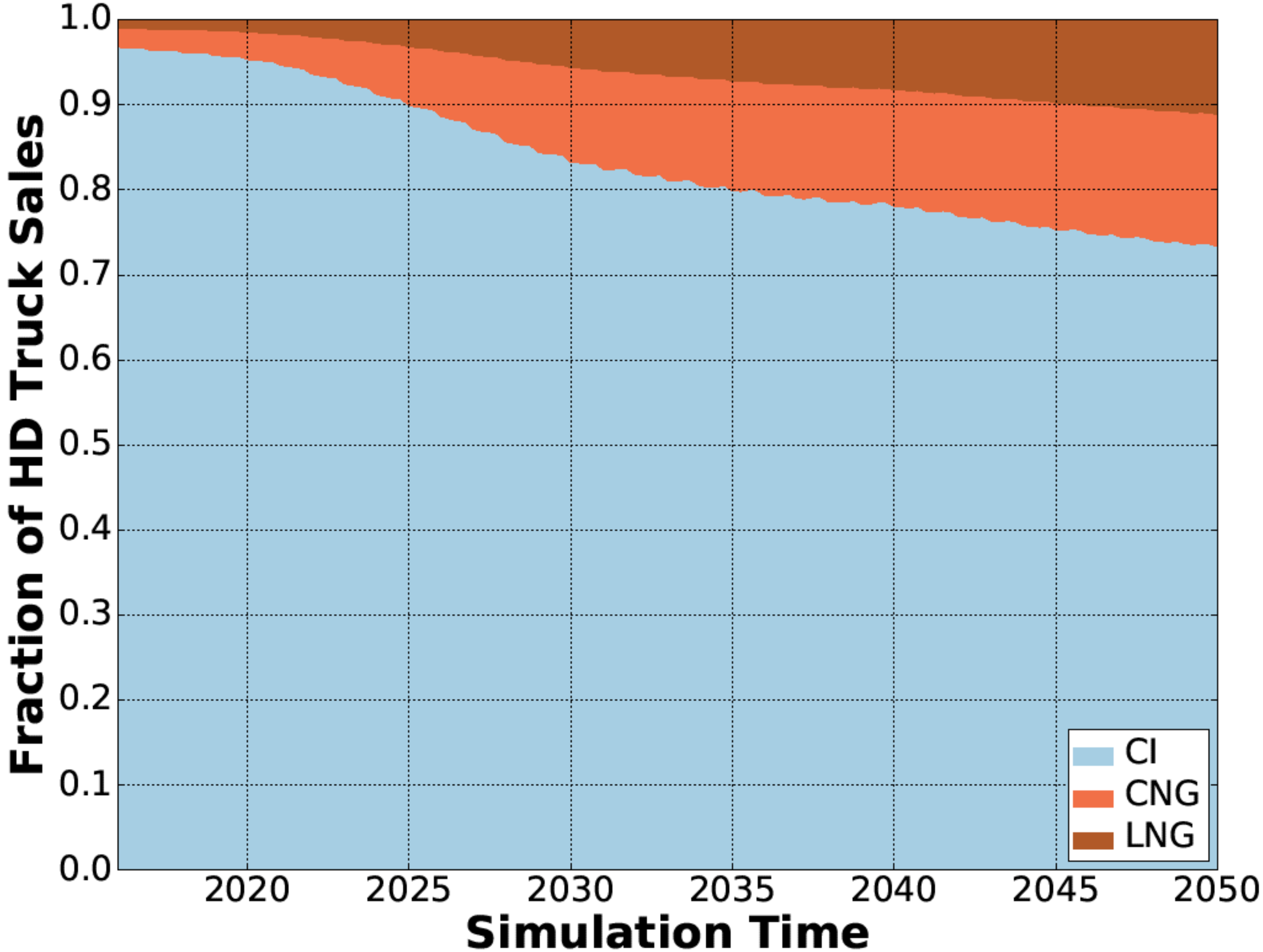
 GHG Emissions Impact



10¢/kWh electricity surcharge negates impact of public charging

A&P HDV Analysis 1: Natural gas incentives only subtly impact heavy-duty vehicle powertrain adoption

- Baseline: Approx. 1/4 HDVs are NG powered



Without NGV Incentive

A&P HDV Analysis 1: Natural gas incentives only subtly impact heavy-duty vehicle powertrain adoption

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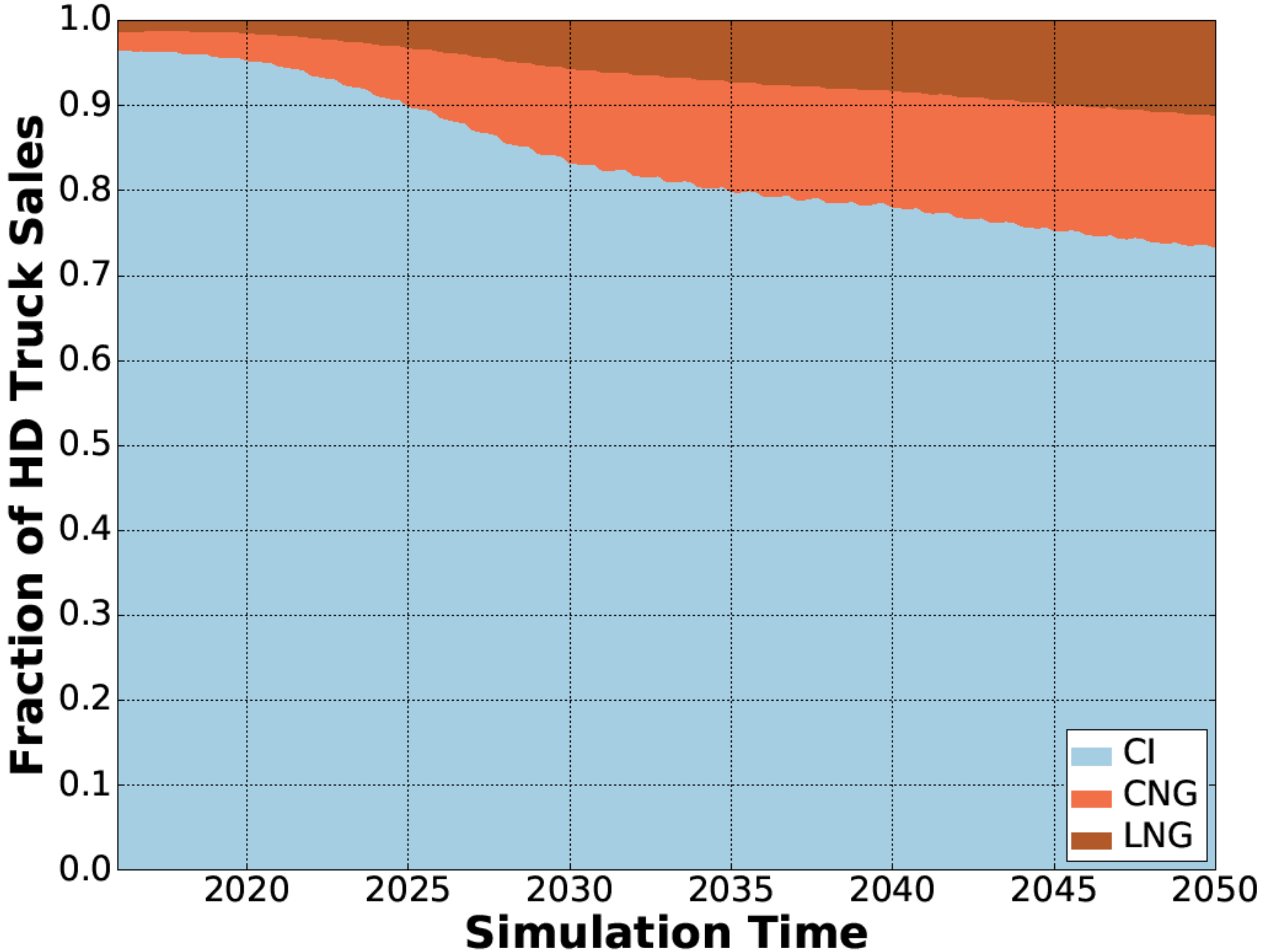

$0.50 NGV Incentive Through 2016

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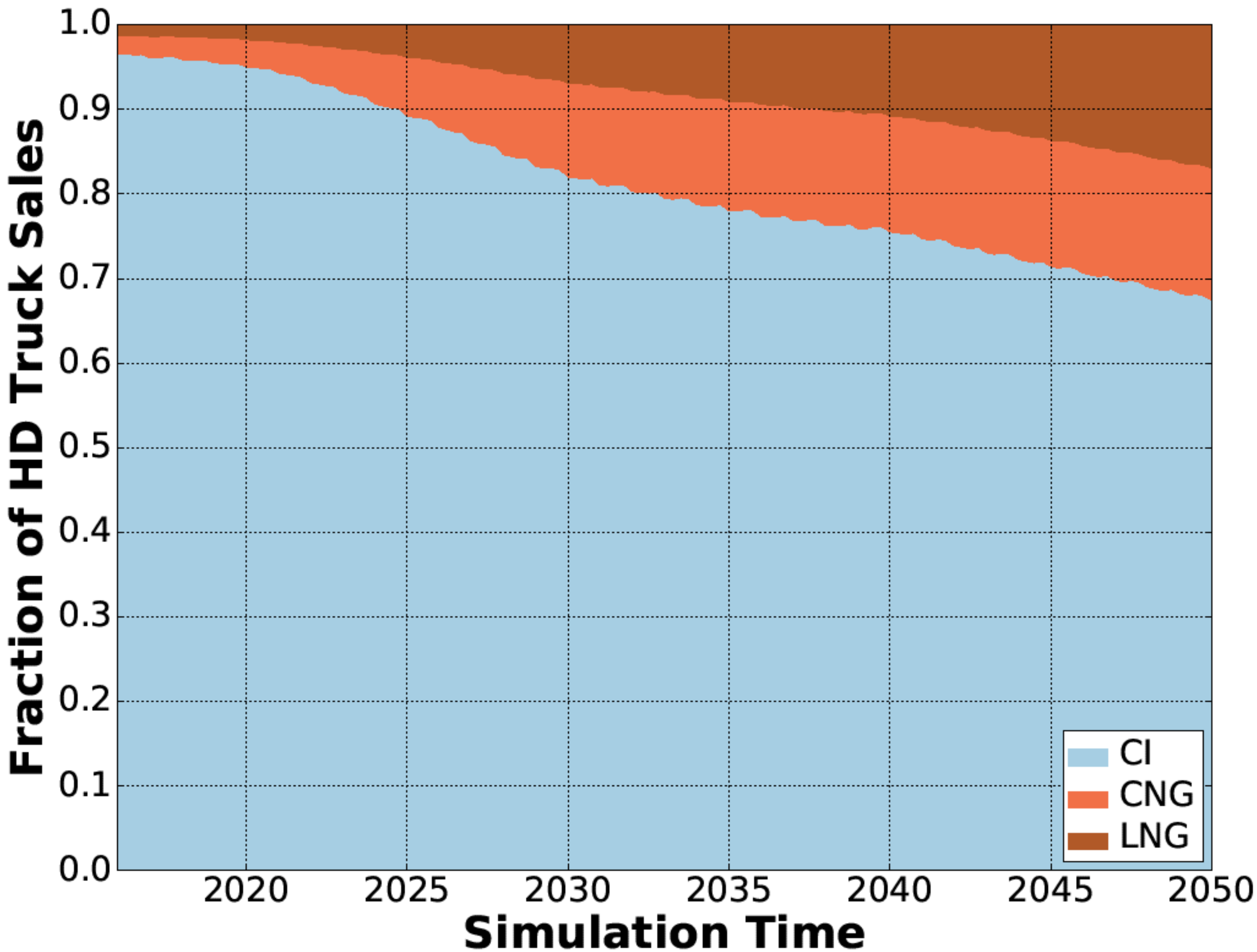

$0.50 NGV Incentive Through 2050

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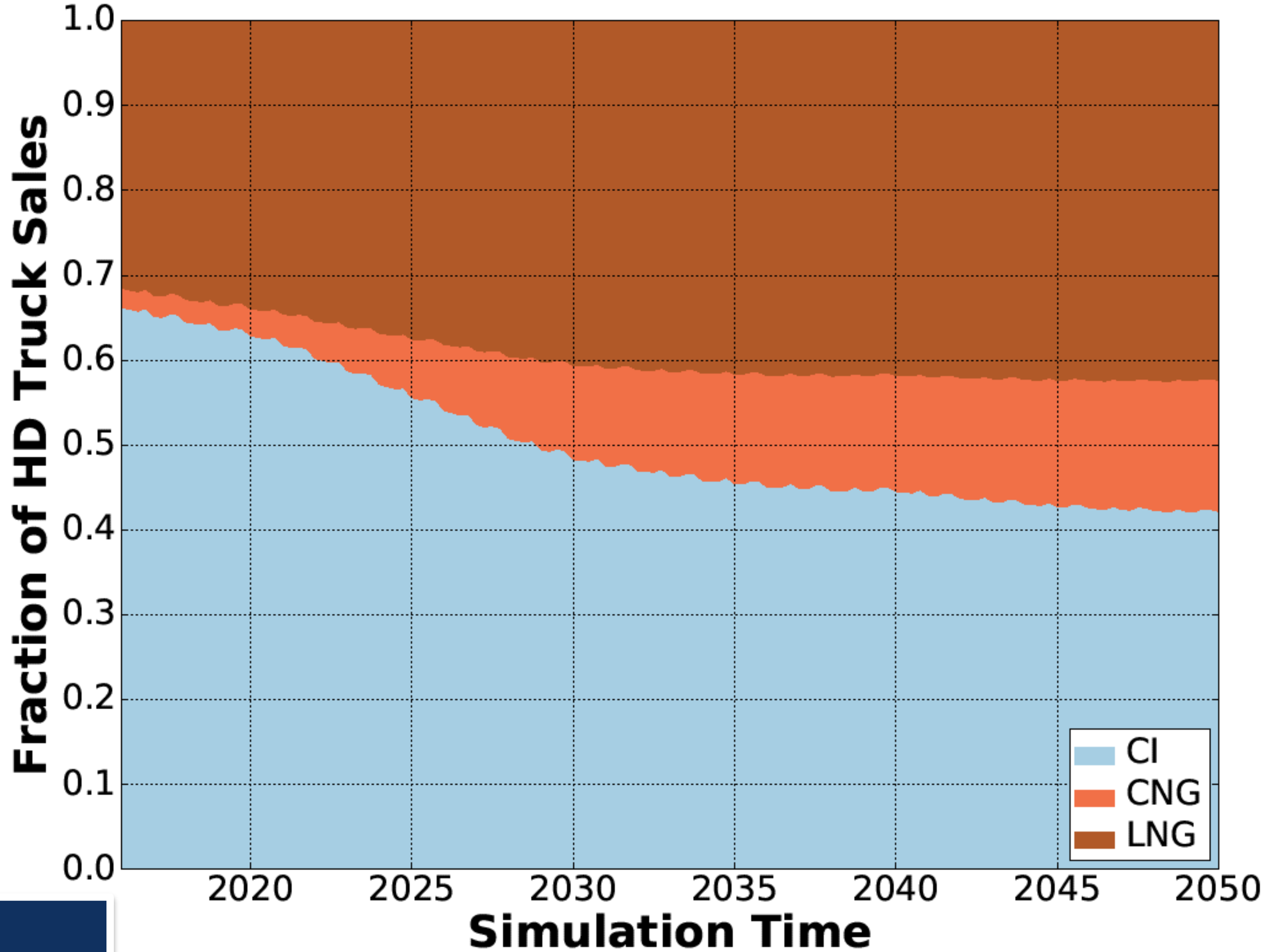

$3.00 NGV Incentive Through 2050

Key Result:
Practical NGV incentives have minimal impact on adoption